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Single use, robust, MEMS based electro-thermal microswitches for redundancy and system reconfiguration

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Abstract

A new type of single use MEMS based thermal microswitch is described and its performance results are presented. The device mechanically breaks a metallic line or locally solders two metallic lines. Switching between the two stable states (on or off) is accomplished by a current pulse through an integrated heater underneath the electrical lines to be interrupted or connected. Some key features are that switches are bistable, integratable and IC compatible. They are compatible with low voltage operation (5 V), no contact resistance (0 Ω for on–off and ∼0.008 Ω for off–on); they have low energy consumption during switching (3.5 mJ for on–off and 130 mJ for off–on); switching current is between 10 and 20 mA for on–off and between 50 and 70 mA for off–on. The minimum switching pulse width is 7 and 300 ms for on–off and off–on, respectively; operation in ambient environment may be possible; predicted lifetime is very long and therefore both switches can be used for long life systems. Batch fabrication using planar processing methods is used.

Keywords: Single use electrothermal microswitches; System reconfiguration; Micropyrotechnics; Microfabrication; Silicon

1. Introduction

Micromechanical switches or relays are important applications of MEMS. Most MEMS based microswitches are based on the deflection of a cantilever or beam supporting an electrical contact towards a second electrode to make electrical contact [1–10]. Numerous designs can be found in the literature to drive the two electrodes into contact and achieve low contact resistance, low power consumption, high isolation or actuation force. Actuation mechanisms are classical, i.e. they are based on electrostatic [1–4], electromagnetic [5,6], thermal [7,8] and piezoelectric [9] forces. The broadest applications for MEMS relays are RF MEMS requiring fast switching (a few microseconds) and high reliability for large numbers of switching operations. Some other published MEMS relay concepts are bistable [10], but are based on cantilever or beam design, and often stick after a long time in the on state.

Other interesting applications of MEMS relays concern redundancy and system reconfiguration that have not been described in the literature. Redundancy switches are commonly used in critical embedded systems: switching is required once with high reliability, and after switching the redundant system must operate with the same stability, performance and reliability as the principal system.

The best-known application field for redundant relays is undoubtedly satellites. Recent trends in the space community for smaller, cheaper satellites require highly integrated, IC compatible, low consumption redundancy switches with no mechanical moving parts, for reliability reasons. The configuration of electronic safety systems has the same requirements as redundancy applications.

This paper presents a new family of electro-thermally actuated microswitches for redundancy and system reconfiguration. The on–off microswitch mechanically breaks an electrical connection. The off–on microswitch locally micro-solders two insulated electrical connections when off–on switching is required. Switching between the two stable states (on or off) is done by injecting a current pulse through an integrated heater underneath the electrical lines. The two microswitches have been designed for batch fabrication using planar processing methods and for single use. They have also been designed to resist relatively high currents. The principles of operation,

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design, fabrication and testing of these electro-thermally actuated microswitches are described in detail.

2. On–off MEMS based microswitch

2.1. Principle of operation

Two methods of breaking the electrical line have been investigated:

- The first method, called a pyrotechnic on–off microswitch is an application of a micropyrotechnic actuator [11]. The electrical line is deposited on a thin dielectric membrane of a micropyrotechnic actuator (see Fig. 1(a and b)). The micro-heater heats the energetic material contained in the cavity underneath the membrane to its ignition temperature. Combustion of the energetic material starts releasing gas that breaks the dielectric membrane and with it the electrical connection.
- The second method, called a thermal on–off microswitch breaks an aluminium line deposited on top of an integrated micro-heater (see Fig. 1(c and d)). When on–off switching is required, the micro-heater heats the aluminium line to its melting temperature (660 °C) causing the aluminium line rupture.

2.2. Design and sizing

For both types of on–off microswitches, an SiO_2 (1.4 μm)/SiN_x (0.6 μm) sandwich forms the thin low stressed membrane that can therefore support the heater and electrical line without breaking [12]. The advantages of this membrane are firstly its thinness and robustness, and secondly its low thermal conductivity resulting in excellent heating performances (see Section 2.4 and Ref. [12]). The micro-heater element is a doped polysilicon coil with a total resistance of 500 Ω. To demonstrate the concept, the silicon cavity and SiO_2/SiN_x membrane are square and the area has been fixed at 1.5 mm × 1.5 mm. However, a cylindrical cavity would be possible and the dimensions could be much smaller if necessary.

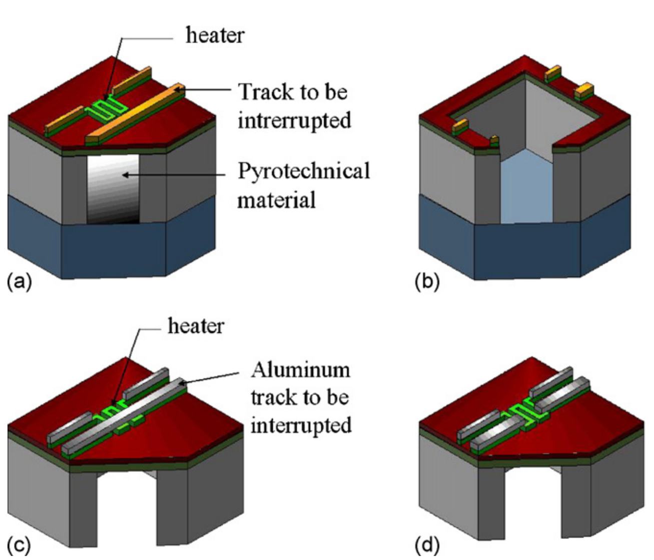

Fig. 1. Illustration of the operating principle of on–off microswitches: pyrotechnic switch (before (a) and after (b) switching) and thermal switch (before switching (c) and after switching (d)) (not to scale).

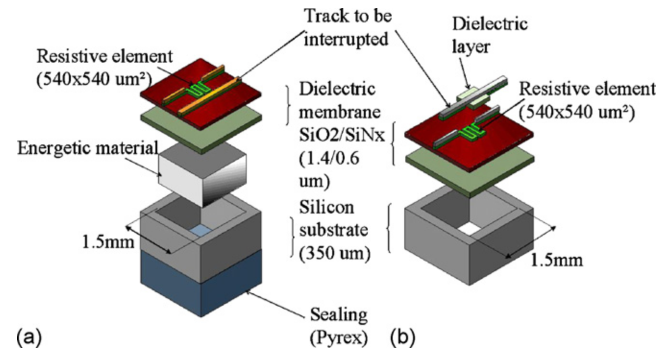

Fig. 2. (a and b) Exploded view of pyrotechnic and thermal on–off microswitches (not to scale).

For the pyrotechnic on–off microswitch, the electrical line can be made of any metal and must be placed near or on top of the micro-heater (see Fig. 2(a)). For the demonstrators, electroplated copper or evaporated aluminium have been deposited at 100 μm from the micro-heater. The high energy material injected inside the micro-cavity underneath the membrane is a composite glycidyl azide polymer (GAP) based propellant.

For the thermal on–off microswitch, the electrical line is simply an aluminium layer deposited on top of the polysilicon micro-heater (see Fig. 2(b)). Aluminium was chosen for its good conductivity (37.7 × 10^4 S/cm) and low melting point (660 °C).

Fig. 2 gives an exploded view of both types of on–off microswitches showing detailed dimensions and material types.

2.3. Fabrication

The process for fabrication of on–off microswitches is completely planar and IC compatible. The 350 μm thick (1 0 0) oriented 4 in. silicon wafer is thermally oxidized to a depth of 1.4 μm at 1150 °C. It is then coated with a 0.6 μm thick coat of silicon rich nitride deposited by low pressure chemical vapor deposition (LPCVD). These two layers form the 2 μm thick low stressed membrane. A 0.5 μm thick polysilicon layer is deposited by LPCVD at 605 °C and N doped by the diffusion of phosphorus. The resulting resistivity is 8 × 10^{-4} Ω cm^{-1}.

2.3.1. Front side processing

The polysilicon layer is patterned using photolithography to define heater resistors and etched by reactive ion etching (RIE). A 0.7 μm thick layer of low stressed oxide is then deposited by plasma enhanced chemical vapor deposition (PECVD) and patterned using photolithography and removed in a HF bath everywhere except on the heater resistance. If the electrical track to be interrupted is located near the heater, the 0.7 μm PECVD deposition is not necessary.

The next step consists of making the metal layer. For pyrotechnic on–off microswitches, a 5 μm thick electrolytic copper is electroplated, whereas for thermal on–off microswitches,